Predictions for two-pion correlations for sqrt(s)=14 TeV proton-proton collisions

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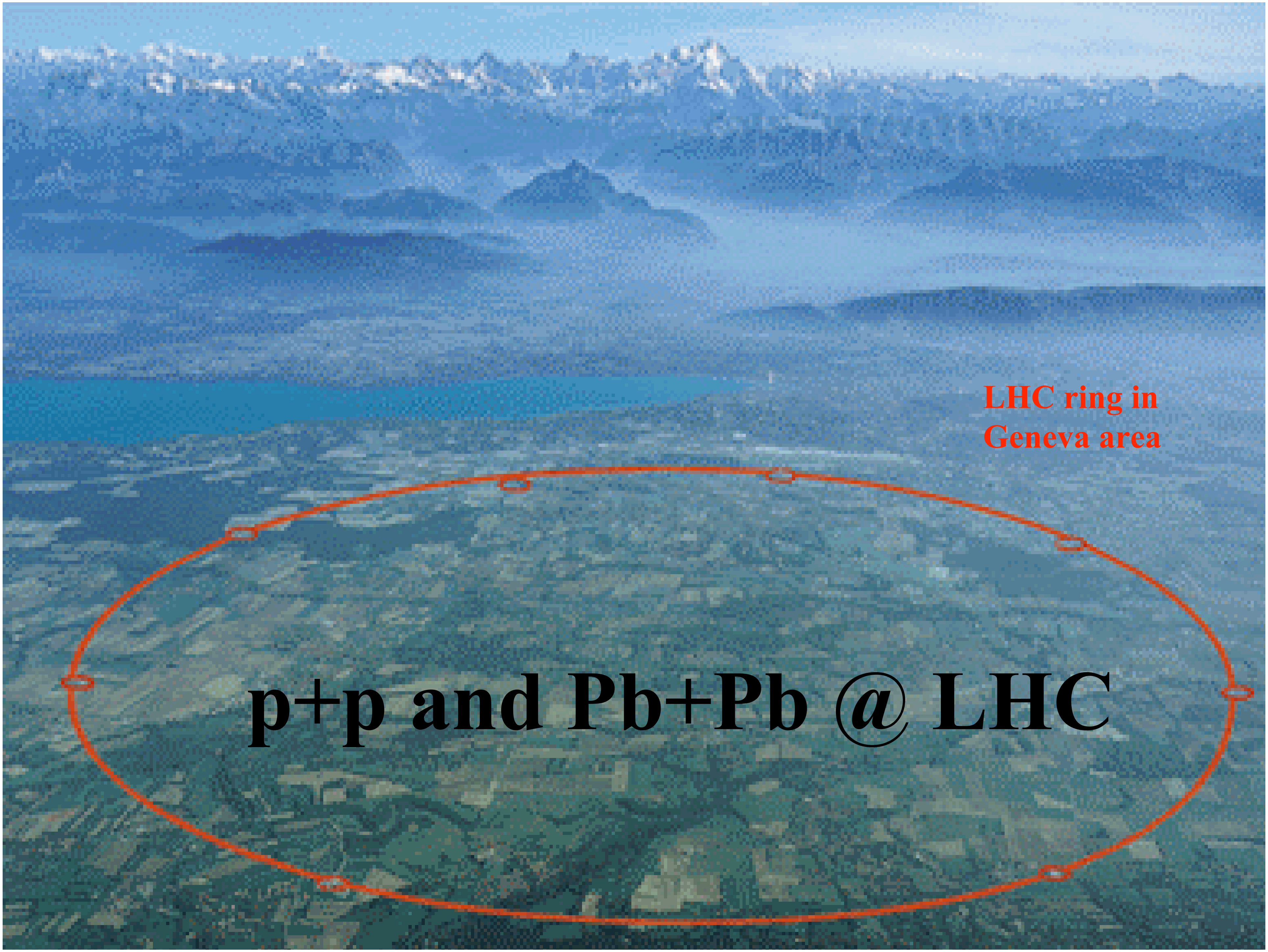
Outline of the talk

- Introduction
- Simple geometric model to give “baseline” predictions for HBT from pp@LHC
- Reality check of model by comparing with Tevatron HBT experiment
- Results of model calculations for sqrt(s)=14 TeV
- Summary

(work to appear in Phys. Rev. C, or see nucl-th/0612098v2)

p+p and Pb+Pb @ LHC



CERN Large Hadron Collider (LHC)

* Located in Switzerland and France – 27 km circumference ring

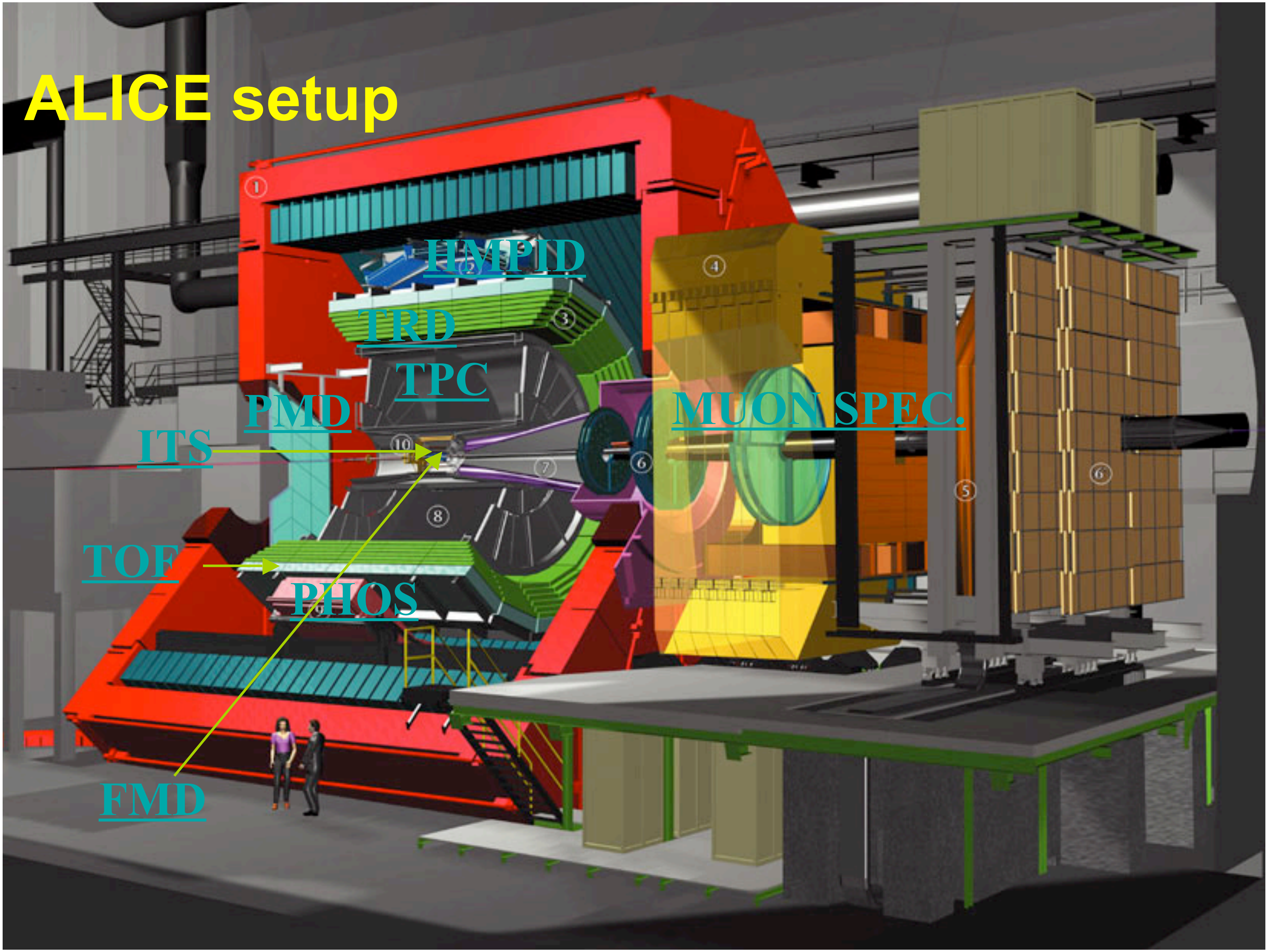
* Maximum C. M. energies and luminosities of colliding beams:

proton + proton:	14 TeV @ 10^{34} collisions/(sec*cm^2)
lead + lead:	5.5 ATeV @ 10^{27} collisions/(sec*cm^2)

* First p-p beam for physics expected by Summer, 2008
  First Pb-Pb beam by ~ end of 2009 (we hope!)
  → better have some interesting p-p physics to do while waiting for Pb-Pb: e.g. HBT, mini-BH, ……..

* Will be the highest energy particle accelerator in the world!
  (Tevatron presently running at Fermilab has a maximum C.M. energy for p-p of 2 TeV)

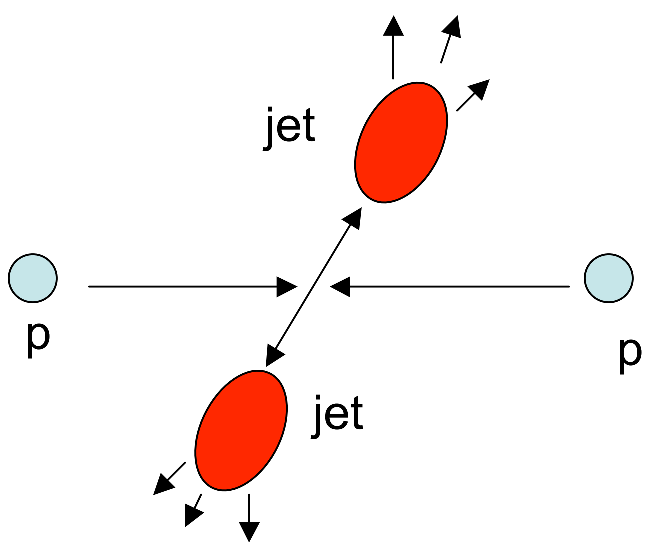
ALICE setup



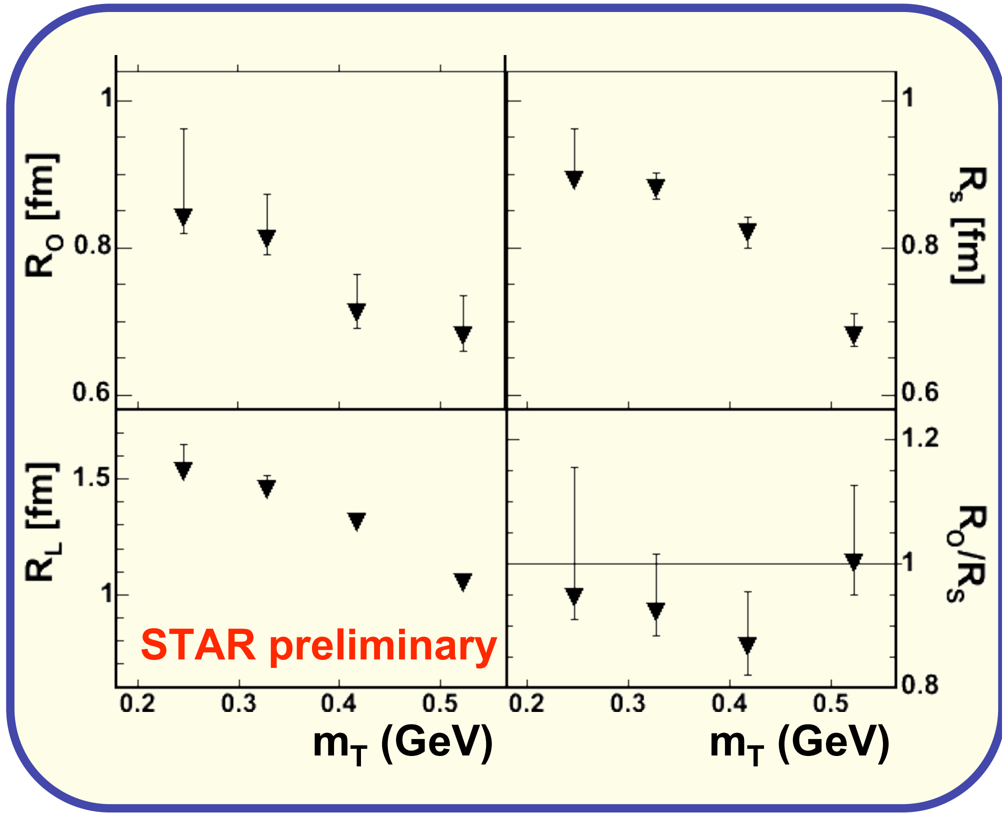
What do we expect to see from pion HBT with p+p @ LHC?

Jet model for HBT with p+p @ FNAL/LHC
Guy Paic and Piotr Skowronski
J. Phys. G: Nucl. Part.. Phys. 31 (2005)

Pion HBT with p+p @ STAR
Zbigniew Chajecki QM05



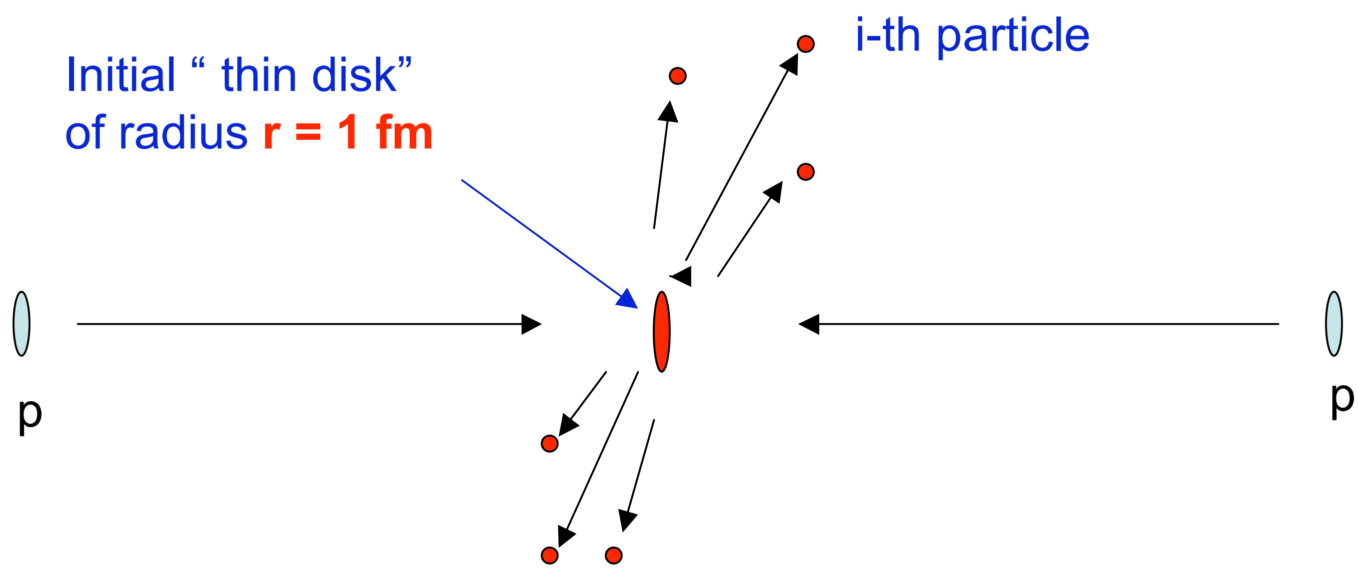
Finds R increases as dN/dy increases, as seen In FNAL data



Goals of the present work

- Use a very simple model to make “baseline predictions” for pion HBT in pp@LHC --> differences between these predictions and LHC data could point to the presence of new physics
- Calculate the 1-d invariant two-pion correlation function $C(Q_{inv})$, where $Q_{inv} = |p_1 - p_2|$ and p_1 and p_2 are pions 4-momenta, to make the predictions simpler to compare with data
- Include final-state hadronic rescattering effects since large hadronic multiplicites (e.g. > 300) are possible at the LHC -- concentrate on events with high multiplicity to enhance this effect
- Do a reality check of the model by comparing results with a Tevatron HBT experiment (Experiment E735) --> if the model fails miserably here already, it’s time for the junk pile!

Simple geometric model for HBT from p+p



* Assume all particles have the same proper time for hadronization, τ, so that the hadronization space-time for each particle is given by "causality", i.e.

$$t_i = \tau E_i/m_i \;\; ; \;\; x_i = x_{oi} + \tau p_{xi}/p_i \;\; ; \;\; y_i = y_{oi} + \tau p_{yi}/p_i \;\; ; \;\; z_i = \tau p_{zi}/p_i$$

(similar to Csorgo and Zimanyi, Nucl. Phys. A512 (1990) applied to e+-e-)

* Take into account hadronic rescattering using a full Monte Carlo rescattering calculation

Other details of the model….

- Use PYTHIA v.6326 to generate hadrons for 1.8 TeV p-pbar or 14 TeV p+p "minimum bias" events
  "final" hadrons from PYTHIA to use: → π, K, N, Δ , Λ , ω, ρ, ϕ, η, η'
- Monte Carlo hadronic rescattering calculation:
  Let hadrons undergo strong binary collisions until the system gets so dilute (since it is expanding) that all collisions cease.
  --> σ(i,j) from Prakash, etc..
  Record the time, mass, position, and momentum of each hadron when it no longer scatters. → freezout condition.
- Calculate $C(Q_{inv}) \sim N_{real}(Q_{inv})/N_{back}(Q_{inv})$ by binning symmetrized pairs of pions assuming plane waves in N_{real} to put in HBT correlations (usual method).
- Fit Gaussian (Tevatron) or more general function (LHC) to $C(Q_{inv})$ to extract parameters R and λ, **or** R, λ, B, and α :
  $C(Q_{inv}) = 1+\lambda \exp(-R^2 Q_{inv}^2)$ **or** $C(Q_{inv}) = 1+\lambda \cos(B Q_{inv}^2) \exp(-R^\alpha Q_{inv}^\alpha)$
- Carry out calcuations for several τ values to see effect on HBT -- expect the smaller values of τ to have the largest rescattering effects

How long does it take to collect a "reasonable" data sample of, for example, $\pi^-\pi^-$ pairs for events with total mult>300 in a detector at the LHC?

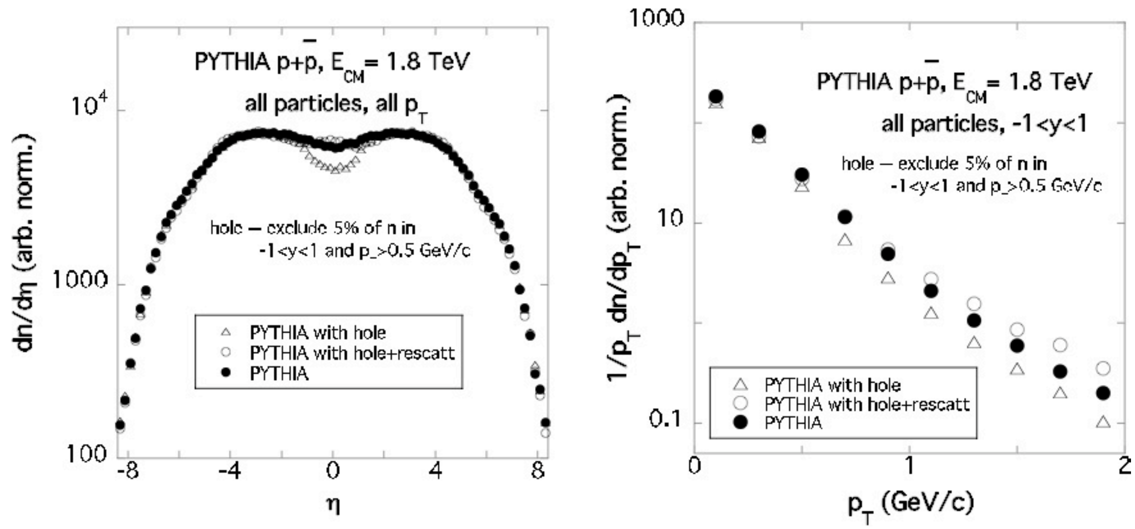
- Assumptions:
  - * reasonable data sample of $\pi^-\pi^-$ pairs for HBT: $\sim 10^6$
  - * detector: ALICE ITS+TPC (~accept. 0.1<pT, -1<y<1; DAQ rate 100Hz)
  - * 1st-year LHC p-p luminosity @ 14 TeV: $L \sim 10^{30}$ cm^{-2} s^{-1}
  - * ~40% of charged particles reconstructed in an event are π^-'s
- From PYTHIA p-p minimum bias run @ 14 TeV
  - * $\sigma_{total} \sim 50$ mb, $\sigma(m>300) = 0.1\ \sigma_{total} \sim 5$ mb
  - * charged hadron multiplicity in ALICE acceptance for m>300: ~ 50/event
- Result:
  - * events/sec= $L\ \sigma(m>300) \sim 5000$ > DAQ rate --> 100 events/sec
  - * $\pi^-\pi^-$ pairs obtained per event ~ $(0.4*50)^2/2 = 200$ --> 20,000 pairs/sec

--> running time to obtain 10^6 pairs = $10^6/20{,}000$ = 50 seconds **~ 1 minute**

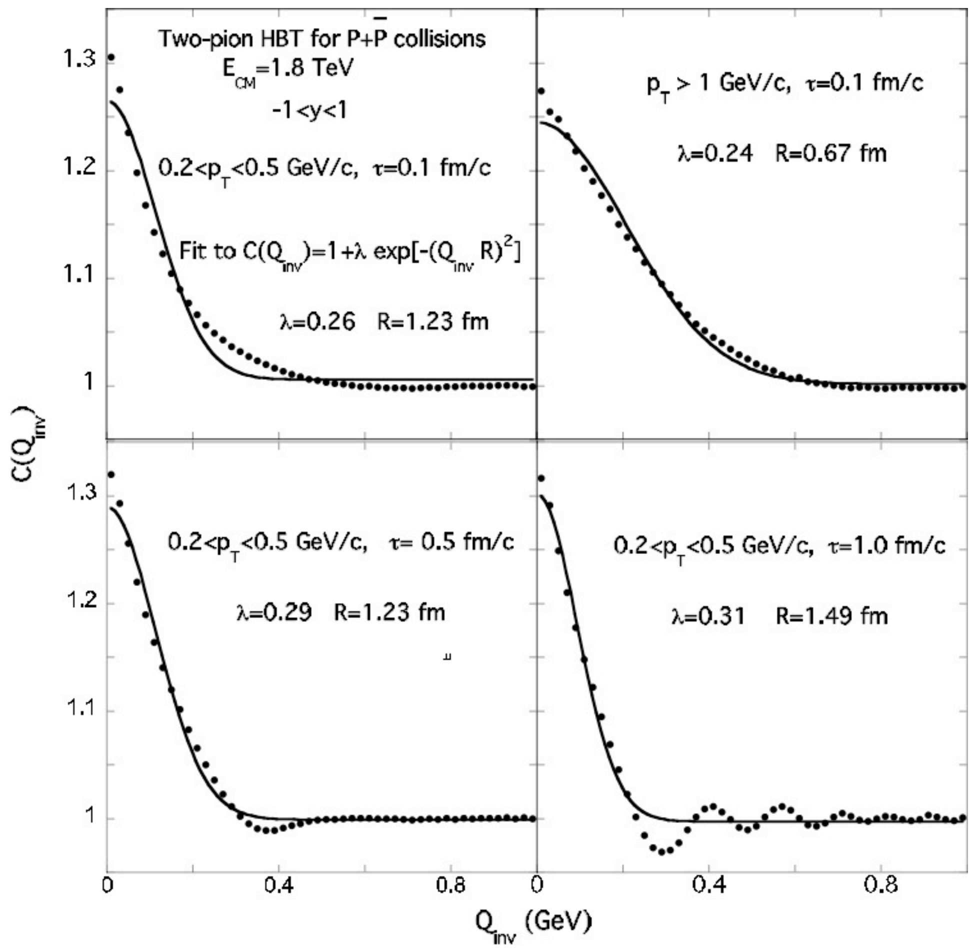
Compare model predictions with Tevatron data as a reality check on the model

- Compare with Experiment E735 which extracted $\pi\pi$ HBT @ sqrt(s)=1.8 TeV in p-pbar collisions using a spectrometer (T. Alexopoulos et al., Phys. Rev. D48,1931(1993))
- Make kinematic cuts on p_T and rapidity to simulate experimental acceptance in the model
- Fit the Gaussian function to $C(Q_{inv})$ to extract R an λ from the model since this was the procedure used in the experiment
- Compare model calculations with τ=0.1, 0.5 and 1.0 fm/c to experiment to see if the data favor one of them over the others

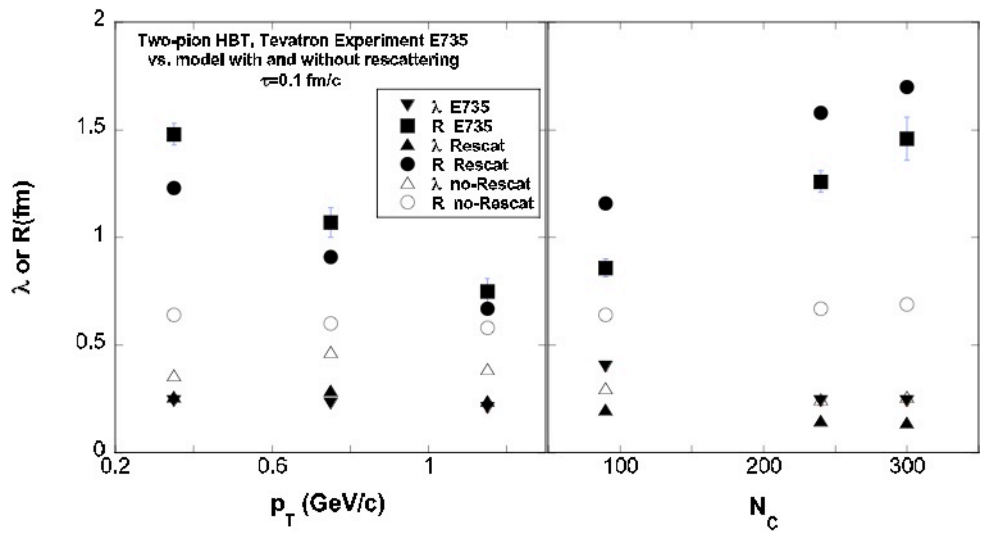
η and p_T distributions from PYTHIA for p-pbar @ 1.8 TeV for 1) direct, 2) with “y-p_T hole”, 3) hole+rescatt. (τ=0.1 fm/c)



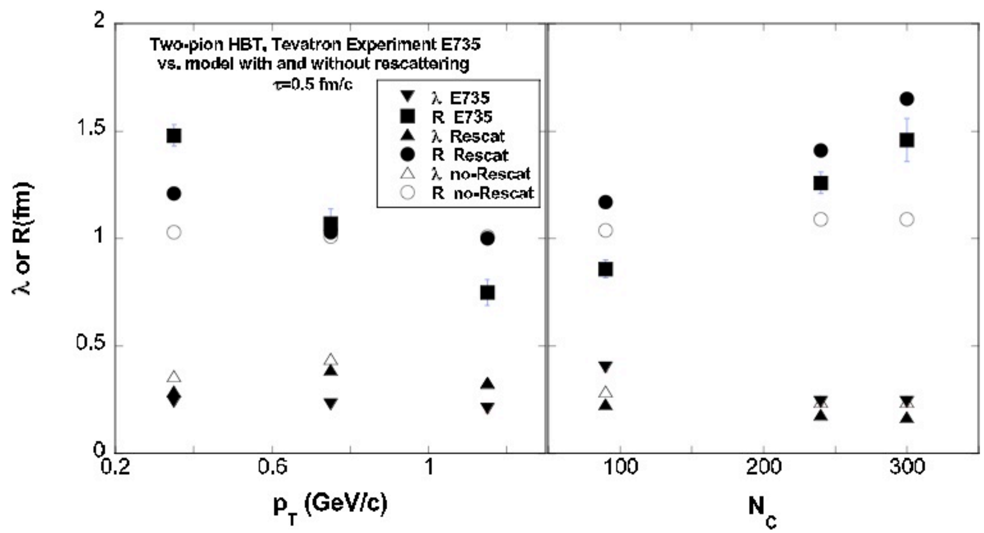
Sample model 2-π correlation functions for τ=0.1, 0.5, 1.0 fm/c for 1.8 TeV p-pbar



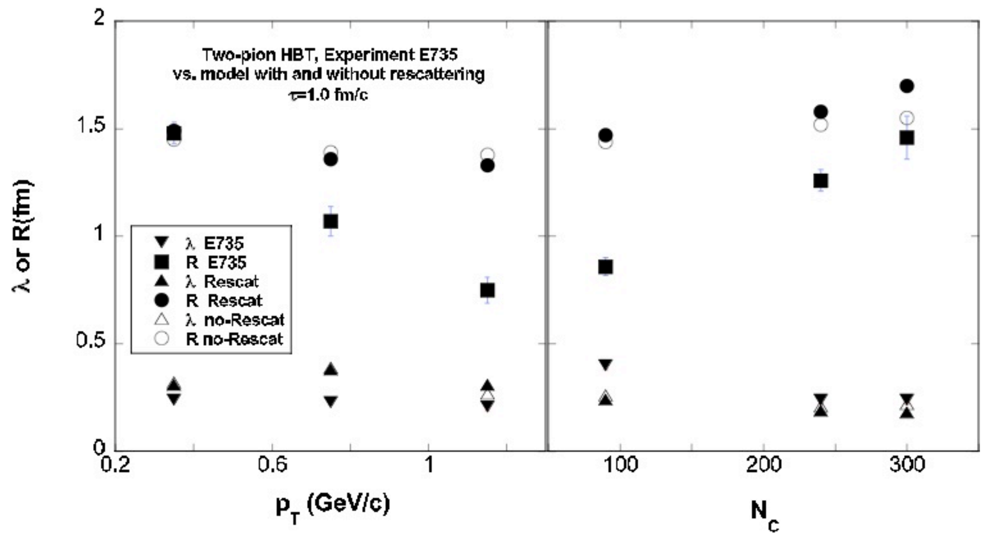
Comparisons of Gaussian fit paramters between E735 and model for τ=0.1 fm/c



Comparisons of Gaussian fit paramters between E735 and model for τ=0.5 fm/c



Comparisons of Gaussian fit paramters between E735 and model for τ=1.0 fm/c



Summary of results for model comparison with Tevatron experiment

- Model best describes the the p_T and multiplicity dependences of the E735 Gaussian HBT parameters for the case of τ=0.1 fm/c with rescattering turned on
- Suggests that hadronization time short in these collisions, i.e. τ<<1 fm/c, and that significant hadronic rescattering effects are present

Model predictions for LHC p-p collisions at 14 TeV

- Make predictions for τ=0.1 and 0.5 fm/c cases
- Employ same "y-p_T hole" method as used for Tevatron calculations
- Fit more general function to $C(Q_{inv})$: (see Csorgo and Zimanyi)

$$C(Q_{inv}) = 1+\lambda \cos(BQ_{inv}^2) \exp(-R^\alpha Q_{inv}^\alpha)$$

where,

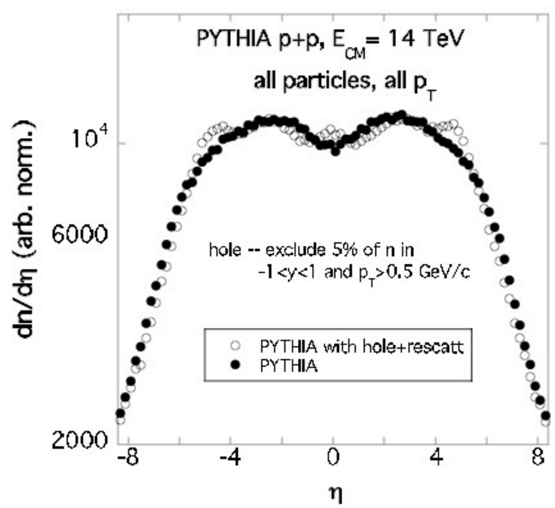
R = "size" parameter

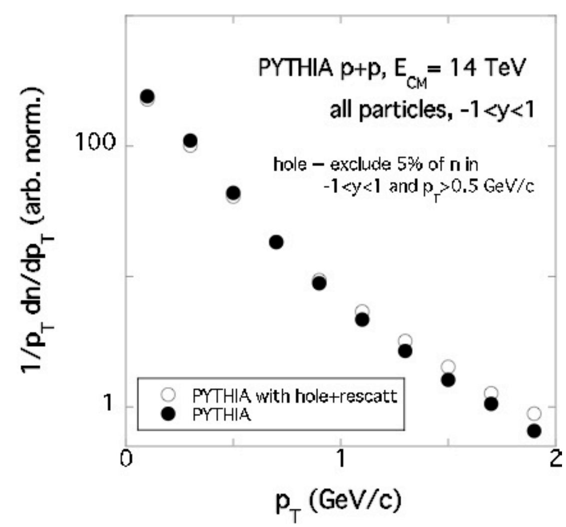
λ = "strength" parameter

B = "oscillatory" parameter, B ~ τ for present model, normally not observed for cases where R>>τ since exp term dominates and quickly damps oscillations

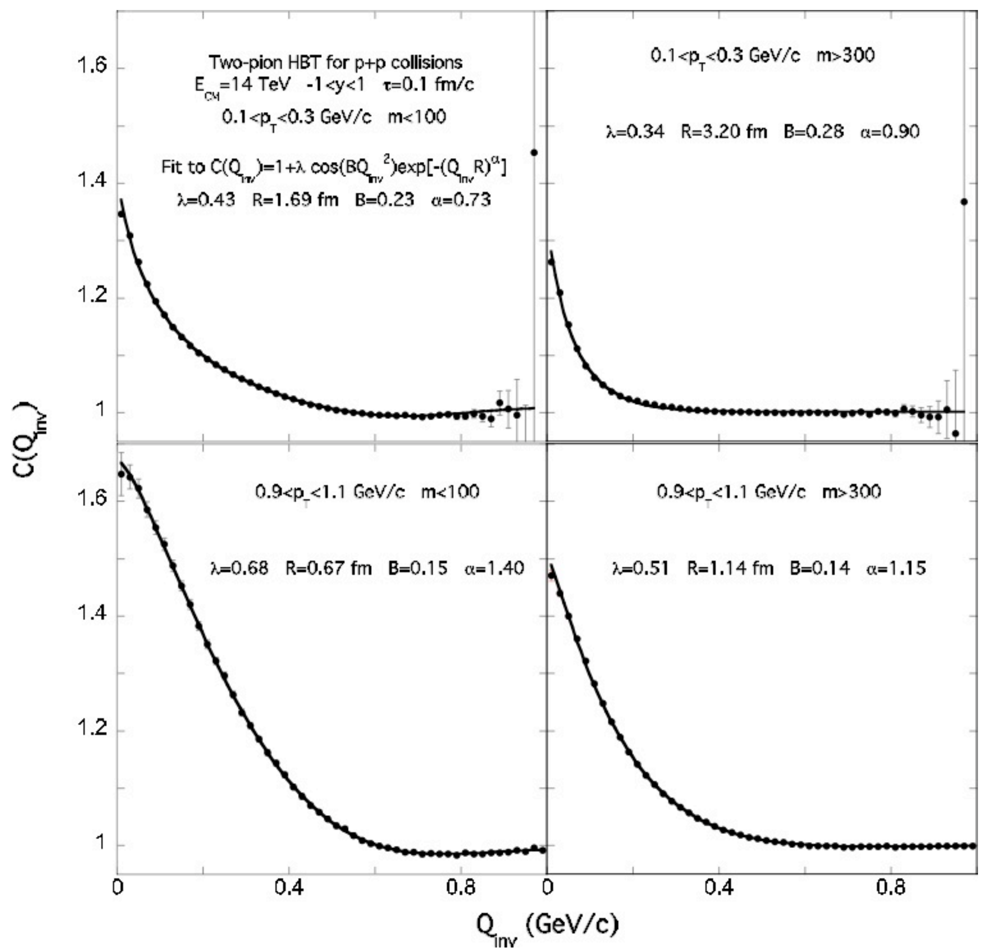
α = "degree of function fall-off" parameter

η and p_T distributions from PYTHIA for p-p @ 14 TeV for 1) direct and 2) hole+rescatt. (τ=0.1 fm/c)

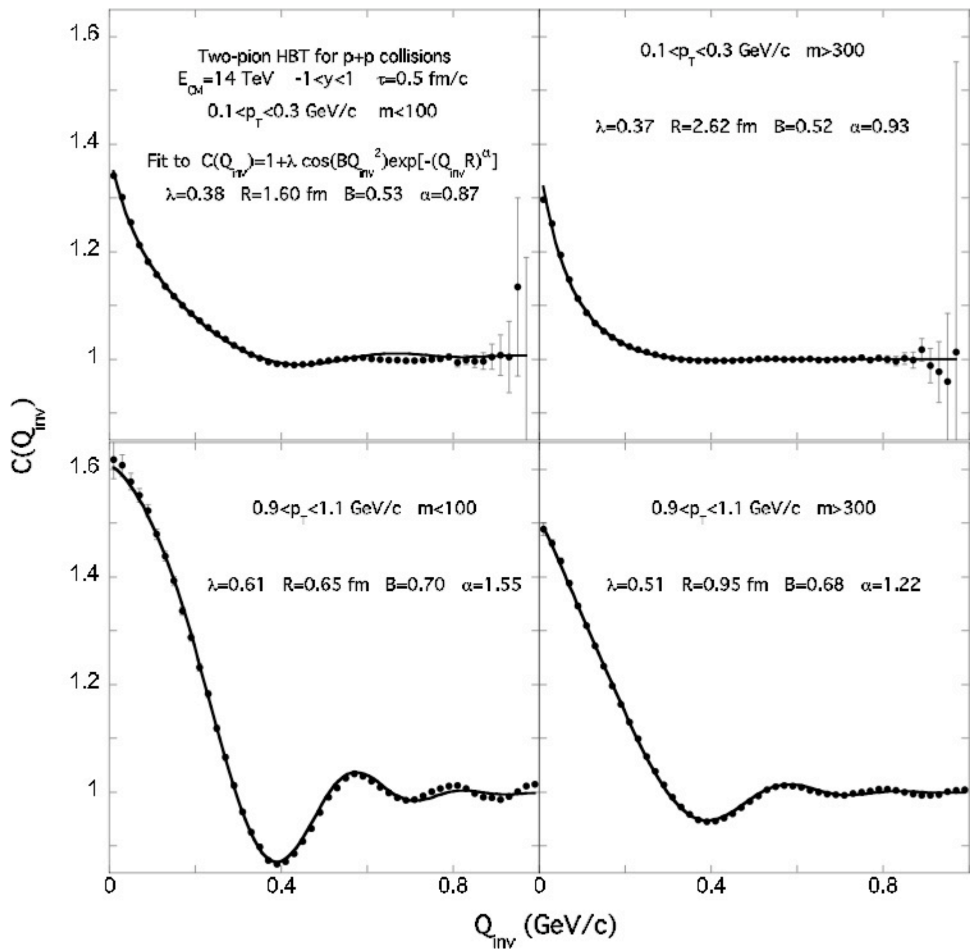




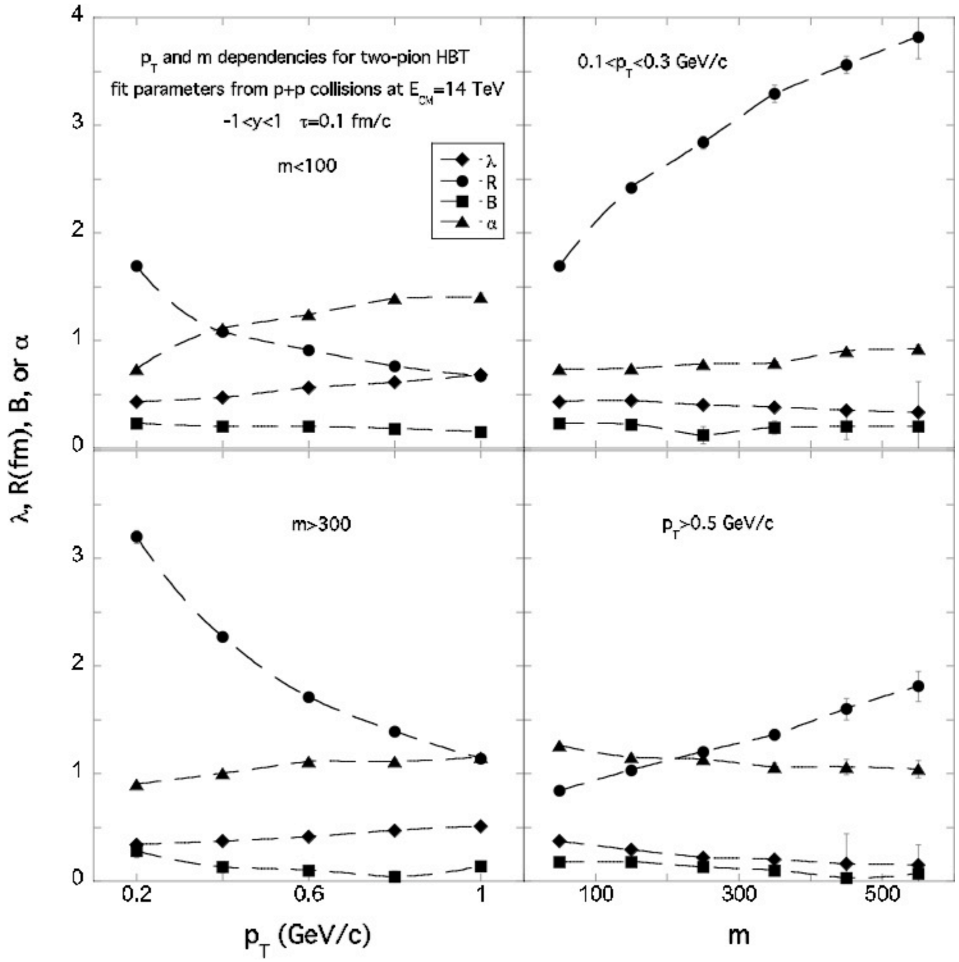
Sample model 2-π correlation functions for τ=0.1 fm/c for 14 TeV p-p with fit to general function



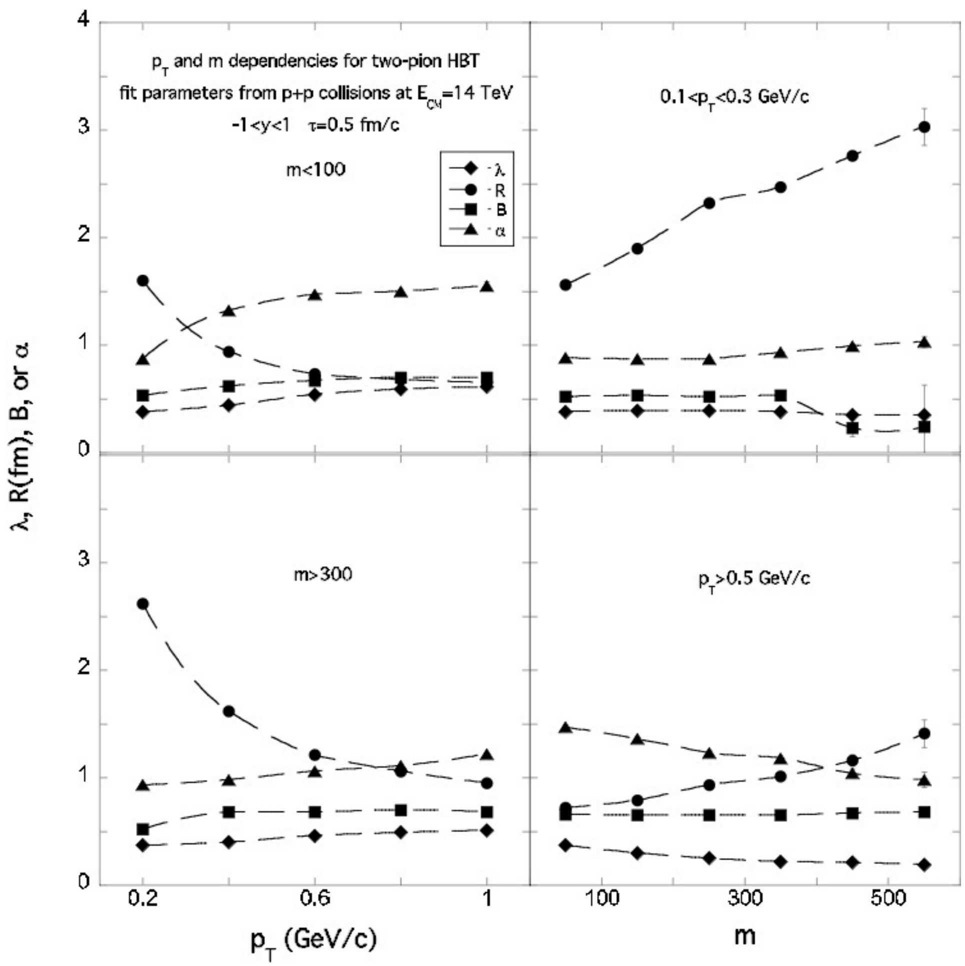
Sample model 2-π correlation functions for τ=0.5 fm/c for 14 TeV p-p with fit to general function



General fit function parameters versus p_T and multiplicity for model with τ=0.1 fm/c for 14 TeV p-p



General fit function parameters versus p_T and multiplicity for model with τ=0.5 fm/c for 14 TeV p-p

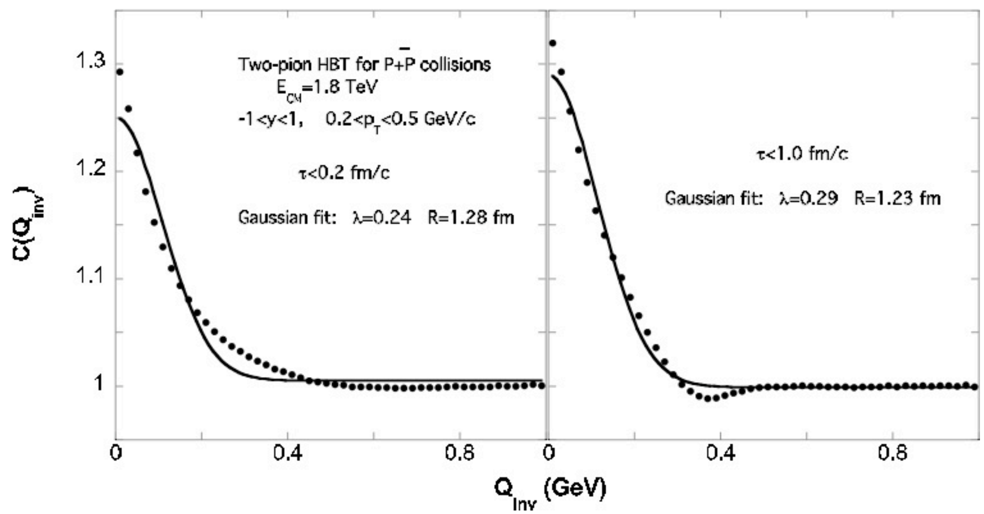


Summary of general fit parameter behavior predicted by model for 14 TeV p-p

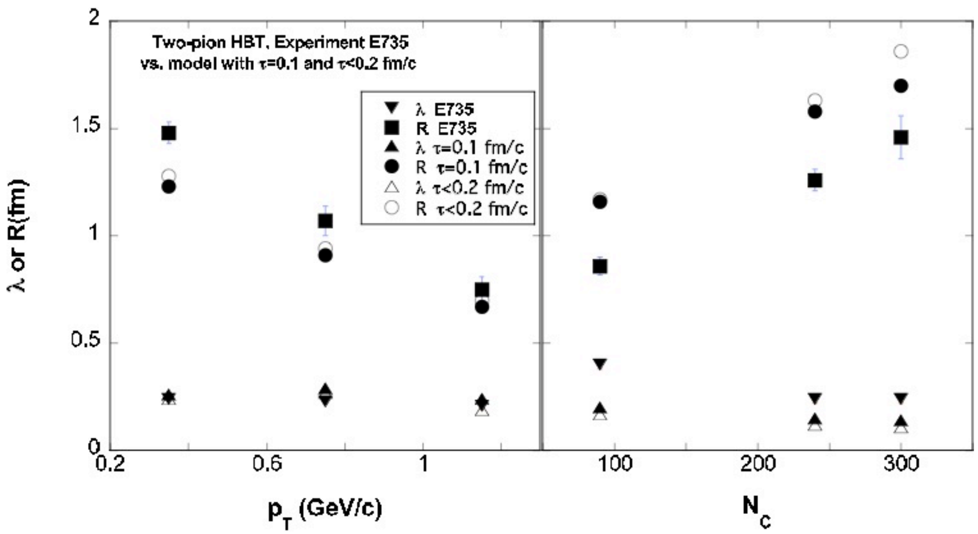
- R -- largest variation for τ=0.1 fm/c case, can increase by 3x for increasing m and decrease by 3x for increasing p_T
- λ -- weak dependencies on kinematical cuts which tend to be opposite those of R; λ<0.5 due to presence of long-lived resonances
- B -- tends to follow the behavior B ~ τ, since noticeable baseline oscillations are seen for the τ=0.5 fm/c case
- α -- similar kinematical dependencies as λ, tends to have values in range 0.7<α<1.5 for both τ=0.1 and 0.5 fm/c

Summary

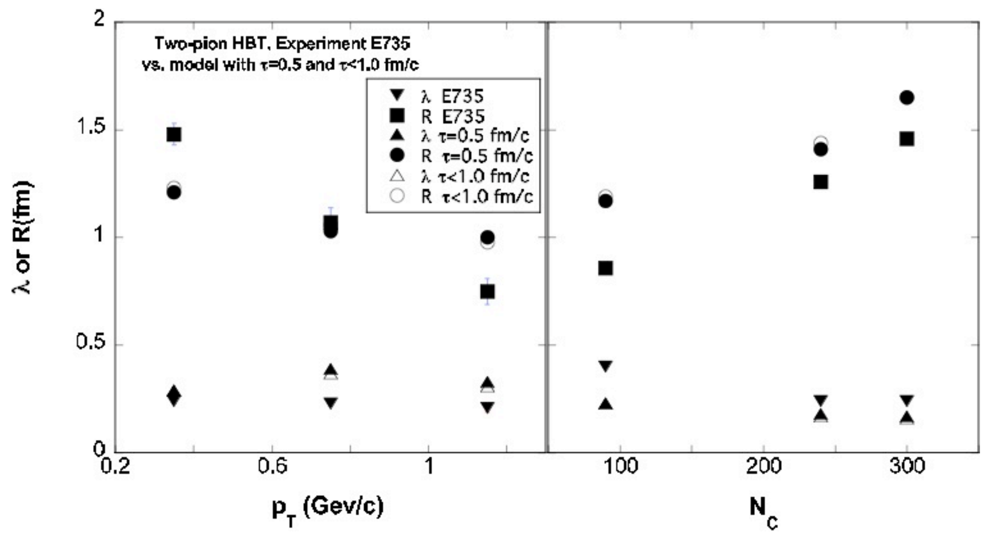
- Within the context of this simple model, results from two-pion HBT @ Tevatron and LHC energies strongly depend on the hadronization proper time, τ
- Comparison of the model with Tevatron data looks reasonable and favors a short hadronization time, τ~0.1 fm/c
- Final-state hadronic rescattering effects appear to be observable for τ<0.5 fm/c in high-energy p-p and p-pbar collisions
- Significant dependences of the HBT parameters on particle multiplicity and p_T bin are predicted by the model to be seen for LHC p-p collisions -- these are enhanced for short τ



Two-pion HBT for P+P̄ collisions
E_CM=1.8 TeV
-1<y<1, 0.2<p_T<0.5 GeV/c
τ<0.2 fm/c
Gaussian fit: λ=0.24 R=1.28 fm
τ<1.0 fm/c
Gaussian fit: λ=0.29 R=1.23 fm
C(Q_inv)
Q_inv (GeV)
1.3
1.2
1.1
1
0
0.4
0.8
0
0.4
0.8



Two-pion HBT, Experiment E735
vs. model with τ=0.1 and τ<0.2 fm/c
λ E735
R E735
λ τ=0.1 fm/c
R τ=0.1 fm/c
λ τ<0.2 fm/c
R τ<0.2 fm/c
λ or R(fm)
2
1.5
1
0.5
0
0.2
0.6
1
100
200
300
p_T (GeV/c)
N_C



Two-pion HBT, Experiment E735
vs. model with τ=0.5 and τ<1.0 fm/c
λ E735
R E735
λ τ=0.5 fm/c
R τ=0.5 fm/c
λ τ<1.0 fm/c
R τ<1.0 fm/c
λ or R(fm)
2
1.5
1
0.5
0
0.2
0.6
1
100
200
300
p_T (Gev/c)
N_C